Available online at www.sciencedirect.com

ScienceDirect

Nuclear and Particle Physics Proceedings 273–275 (2016) 2811–2813

www.elsevier.com/locate/nppp

Measurement of the *Wt* Production Cross-Section in Dilepton Events with the ATLAS Detector

Sebastian Mergelmeyer[a] on behalf of the ATLAS Collaboration

[a] *Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn, Nußallee 12, 53115 Bonn, Germany*

Abstract

Single top-quark production, accounting for $\sim 1/3$ of the overall top-quark production at the LHC, constitutes an excellent probe of the *W*-*t*-*b* coupling, which is sensitive to certain types of new physics. One important production mode in the Standard Model is the creation of a single top quark in association with a *W* boson. The close similarity of its final state to that of top-quark pair production, which has a more than 10 times larger production cross-section, makes the measurement a challenging endeavour. Hence multivariate techniques are appropriate to identify the *Wt* signal. The results of the latest *Wt* cross-section measurement with the ATLAS detector, based on 20 fb^{-1} of *pp*-collision data at $\sqrt{s} = 8$ TeV, are presented.

Keywords: LHC, ATLAS, single top, cross-section, CKM matrix

1. Introduction

While top quarks are produced at the LHC predominantly in pairs via the strong interaction, production of single top quarks accounts for approximately one third of the overall top-quark production. A fifth thereof is attributed to the associated production of a single top quark and a quasi–real *W* boson (*Wt* production). Due to its small cross-section at the Tevatron, it was first observed at the LHC in summer 2013 [2].

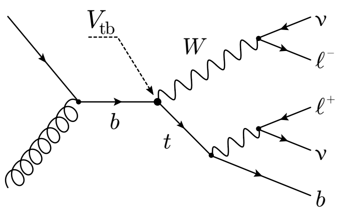

Figure 1: Feynman diagram for *Wt* production at leading-order perturbative QCD with decay into two charged leptons, two neutrinos and a *b*-quark.

Since the production of a single top quark involves a *W*-*t*-*b* vertex, as indicated in Fig. 1, it constitutes an excellent probe of the *W*-*t*-*b* coupling, which is sensitive to certain types of physics beyond the Standard Model (SM). The measurement of *Wt* production in particular is complementary to other single top production channels. *Wt* production also plays an important role as background to Higgs measurements and searches for new physics.

These proceedings review the latest measurement of *Wt* production [1] with the ATLAS detector [3], based on 20.3 fb^{-1} of *pp*-collision data at $\sqrt{s} = 8$ TeV recorded in the year 2012.

2. Selection

Events where both the top quark and the *W* boson decay leptonically provide a clean signature in the detector. Exactly one electron and one oppositely charged muon with a transverse momentum of $p_T > 25$ GeV in the central region of the detector, $|\eta| < 2.5$, were required. Both leptons had to be isolated, in order to suppress non-prompt leptons. Jets were reconstructed using the anti-k_T algorithm with a distance parameter of 0.4. Jets that did not have a transverse momentum of $p_T > 30$ GeV were ignored, as were jets outside of the central region of the detector. Since the *b*-quark from

http://dx.doi.org/10.1016/j.nuclphysbps.2015.10.072

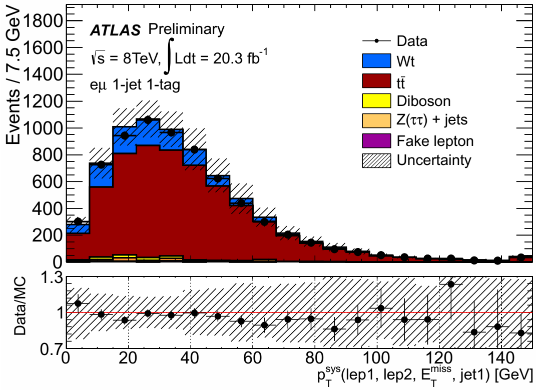

Figure 2: Distribution of the vector sum of the transverse momenta of both charged leptons, the neutrinos, and the leading jet. The uncertainty band is the quadratic sum of all systematic uncertainties [1].

the top-quark decay fragments into a jet, at least one of the selected jets was required to be b-tagged, with a tagging efficiency of 80%. Events with exactly one jet were taken for the *signal region*, where Wt production was estimated to contribute 16% of the events. The *$t\bar{t}$-enriched control region* comprised events with exactly two jets.

3. Physics Processes

The SM predicts a cross-section of $\sigma(pp \to Wt+X) = 22.4 \pm 1.5\,\text{pb}$ for Wt production at $\sqrt{s} = 8\,\text{TeV}$ [4]. This cross-section was calculated at next-to-leading order (NLO) in perturbative QCD, including resummation of the next-to-next-to-leading logarithmic (NNLL) soft gluon terms, and its uncertainty accounts for variations of the scales and the parton distribution function of the proton. A top-quark mass of 172.5 GeV was assumed. The shape of the Wt signal was estimated using the Monte Carlo generator Powheg coupled with Pythia.

The dominant irreducible background was top-quark pair production, making up 80% of the signal region, and 93% of the $t\bar{t}$-enriched control region. It was simulated using the same setup as for Wt production, and then normalized to the SM prediction, $\sigma(pp \to t\bar{t}+X) = 253^{+13}_{-15}\,\text{pb}$ (NNLO QCD). $t\bar{t}$ and Wt production have very similar final states, making it hard to distinguish them from each other. Since the two processes also mix, it was verified that the impact of their interference on the results was negligible.

Di-boson production (WW, ZZ, WZ), and the production of single Z bosons in association with jets were each expected to contribute less than 2% to the signal region. The simulated shapes were normalized using calculations at NLO respectively NNLO in QCD.

If at least one of the selected leptons was of non-prompt origin, such as semi-leptonic decays or jets being misidentified as electrons, the event was assigned to the *fake lepton* background. This background was estimated using a data-driven technique, and was found to contribute less than 1% to the signal region.

4. Analysis Procedure

Since the Wt signal is inherently difficult to distinguish from the $t\bar{t}$ background, an approach based on a multivariate analysis method was chosen. In particular Boosted Decision Trees (BDTs) were employed to construct a discriminant between Wt and $t\bar{t}$, using variables derived from kinematic quantities of the selected leptons and jets, and missing energy. Two BDTs were trained separately in the signal and control regions, each with about 20 input variables. The most powerful variable in the signal region was the vector sum of the transverse momenta of the charged leptons, the neutrinos and the leading jet. Its distribution is shown in Fig. 2. The output distributions of the BDT classifiers are shown in Fig. 3.

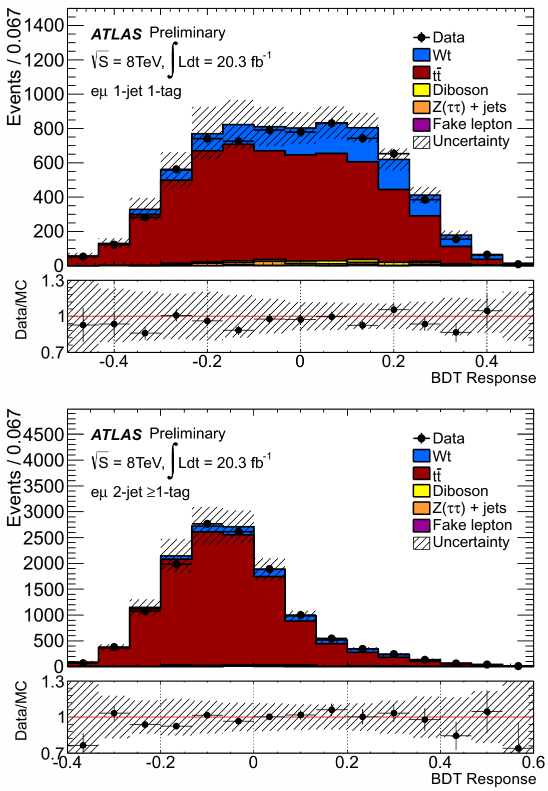

Figure 3: Distributions of the response of the BDT classifiers in the signal (top) and control (bottom) regions [1].

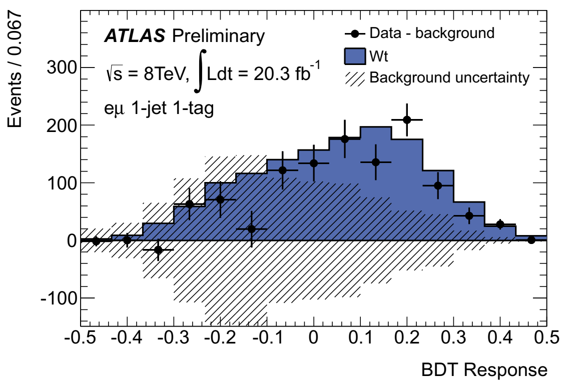

Figure 4: Background-subtracted distribution of the response of the BDT classifier in the signal region, after scaling signal and backgrounds by the fit results. The uncertainty band is the quadratic sum of all background uncertainties [1].

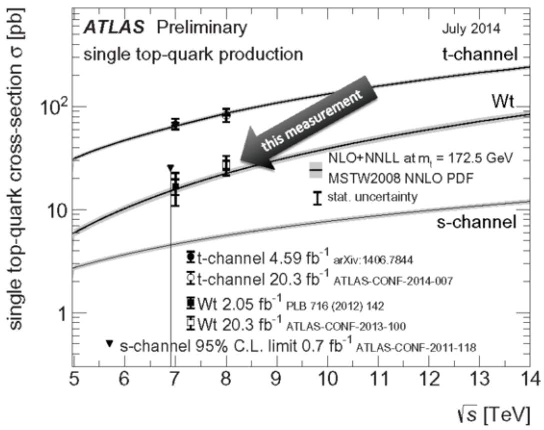

Figure 5: Summary of single top production cross-section measurements at ATLAS, compared to SM predictions.

A binned profile likelihood fit of the expected distributions of the BDT response to data was then performed to determine the strength of the *Wt* signal. The normalizations of the backgrounds were constrained according to the respective theoretical cross-sections and their uncertainties. As shape and normalization of the discriminant proved sensitive to some sources of experimental systematic uncertainties, the terms for the corresponding nuisance parameters were included in the likelihood. Based on ensembles of pseudo-experiments, the effect of all systematic uncertainties on the measured cross-section was expected to be 25%. The major uncertainties were due to jet energy scale (12%), modelling of the *Wt* signal (11%) and $t\bar{t}$ background (9%), b-tagging (9%), and reconstruction of missing transverse energy (7%).

After subtraction of the backgrounds, the BDT response in the signal region, depicted in Fig. 4, showed a clear excess, consistent with the expectation for *Wt* production. In order to determine the discovery significance of the measurement, ensembles of pseudo-experiments were used. The ratio of the likelihood maximized for the signal-plus-background hypothesis to that of the background-only hypothesis was taken as test statistic. The SM prediction for the *Wt* signal was assumed for the signal hypothesis.

The *Wt* production cross-section is sensitive to the CKM matrix element $|V_{\mathrm{tb}}|$ (see Fig. 1). Assuming that *Wt* production through V_{td} and V_{ts} is small, and that $\mathcal{B}(t \to Wb) \approx 1$, $|V_{\mathrm{tb}}|$ can be directly calculated from the ratio of the measured to the theoretical cross-section. No assumption on the unitarity of the CKM matrix, or the number of quark generations is required.

5. Results

The cross-section for the associated production of a single top quark and a *W* boson has been measured in 20.3 fb^{-1} of *pp*-collision data recorded with the ATLAS detector at $\sqrt{s} = 8$ TeV:

$$\sigma(pp \to Wt + X) = 27.2 \ \pm 2.8\,(\mathrm{stat.}) \ \pm 5.4\,(\mathrm{syst.})\,\mathrm{pb}\,,$$

which is 20% larger than predicted (see Sect. 3), but well within the uncertainties. The result corresponds to an observed significance of 4.2 standard deviations for 4.0 expected.

The cross-section has been interpreted in terms of the CKM matrix element $|V_{\mathrm{tb}}|$:

$$|V_{\mathrm{tb}}| = 1.10 \ \pm 0.12\,(\mathrm{exp.}) \ \pm 0.03\,(\mathrm{theory})\,.$$

Fig. 5 summarizes the results of this and other measurements of single top production cross-sections at ATLAS. They are consistent with each other and with the Standard Model predictions.

References

[1] ATLAS Collaboration, ATLAS-CONF-2013-100. URL `http://cdsweb.cern.ch/record/1600799`

[2] CMS Collaboration, Observation of the associated production of a single top quark and a *W* boson in *pp* collisions at $\sqrt{s}$ = 8 TeV, Phys. Rev. Lett. 112 (2014) 231802. doi:10.1103/PhysRevLett.112.231802.

[3] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003. doi:10.1088/1748-0221/3/08/S08003.

[4] N. Kidonakis, Two-loop soft anomalous dimensions for single top quark associated production with a *W* or *H*, Phys. Rev. D 82 (5) (2010) 054018.